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Watershed sediment yield reduction through soil conservation in a West-Central Oklahoma watershed†

Jurgen D. Garbrecht* and Patrick J. Starks
USDA, ARS, Grazinglands Research Laboratory 7207 West Cheyenne Str., El Reno, Oklahoma, 73036, USA

ABSTRACT

Soil conservation practices on the Fort Cobb Reservoir watershed in West-Central Oklahoma were limited before the 1950s. However, extensive soil conservation measures were implemented in the second half of the 20th century to protect agriculturally fertile but erosion-prone soils. Fortuitously, the U.S. Geological Survey (USGS) collected instantaneous suspended-sediment and discharge measurements on major tributaries within the watershed in 1943–1948 and again in 2004–2007, called pre- and post-conservation periods respectively. These measurements offered the opportunity to compare channel suspended-sediment yield before and after implementation of conservation practices. A separate suspended sediment-discharge rating curve was developed for the pre- and post-conservation period. Average annual suspended-sediment yield at a U.S. Geological Survey gauging station near the watershed outlet was estimated by evaluating each sediment-discharge rating curve with the 18-year long daily discharge record at that gauging station. Average annual suspended-sediment yield was estimated to be 760 [Mg/yr/km^2] and 108 [Mg/yr/km^2] for the pre- and post-conservation periods, respectively. The substantial reduction in suspended-sediment yield was related to land use and management changes and the wide range of conservation practices implemented in the second half of the 20th century. Even though it generally is difficult to identify impacts of upstream conservation practices on sediment yield at the watershed outlet during the short time-span of a particular conservation project, targeted and widespread conservation efforts in the Fort Cobb Reservoir watershed have led, over 60 years, to a sizable and measurable reduction in watershed sediment yield. Published in 2009 by John Wiley & Sons, Ltd.

KEY WORDS sediment yield; sediment; conservation; watershed; runoff; soil erosion; water quality

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INTRODUCTION

Over half a century of soil and water conservation research and demonstration projects in agricultural watersheds left little doubt that conservation at field and small catchment scales (∼1 to 100 [ha]) is highly effective at reducing overland soil erosion and sediment delivery to channels (Wilson and Browning, 1945; Smith, 1946; Meyer and Mannering, 1963; Wischmeier and Smith, 1978; Laflen and Colvin, 1981; Stein *et al.*, 1986; Berg *et al.*, 1988; McGregor *et al.*, 1990). However, soil conservation and channel stabilization do not always translate into an immediate response of measurable sediment yield reduction at a downstream point on the main channel of a large watershed (> ∼ 10′000 [ha]) (Allen and Welch, 1971; Mead, 1988; Trimble, 1999; Santhi *et al.*, 2005; Shields, 2008a). In this study, plausible reasons for this lag in watershed sediment-yield reduction to upland conservation practices are briefly reviewed, and a unique opportunity to demonstrate measurable conservation impacts on the Fort Cobb Reservoir watershed (∼79′000 [ha]) was seized upon by contrasting runoff and suspended-sediment yield measurements with similar measurements taken more than half a century earlier. Suspended-sediment yield reduction over 60 years was estimated and interpreted in terms of land use conversion, soil conservation practices, urban development, and variations in climate.

BACKGROUND

The perceived slow, delayed, and often limited sediment yield reduction at the outlet of large watersheds as a result of upstream conservation practices can be attributed to several conservation programme implementation factors. First, early conservation programmes had eligibility criteria that encouraged broad participation and equal access, and did not place enough emphasis on placement or targeting of conservation practices to areas of high erosion potential within a watershed (Cox, 2008). Second, the effects of conservation or best management practices, while highly effective at the application sites, can lead to a minimal response at the watershed outlet if practices are not targeted and applied over a large enough portion of the watershed (Sharpley and Rekolainen, 1997; Santhi *et al.*, 2005). Third, the track record of voluntary farmer participation in conservation programmes has proven to be generally modest, depending

* Correspondence to: Jurgen D. Garbrecht, USDA, ARS, Grazinglands Research Laboratory, 7207 West Cheyenne Str., El Reno, Oklahoma, 73036, USA. E-mail: jurgen.garbrecht@ars.usda.gov

on farm size, perceived economic advantages of adoption of conservation programmes, implementation effort, and other factors (McLean-Meyinsse, 1994; Hoard and Brewer, 2006; Lambert *et al.*, 2006). Last, but not least, funding for conservation programmes is administered on an annual basis and spread over several years, leading to a gradual enrollment and corresponding incremental implementation of conservation practices, all adding to the lag time to full realization of conservation goals. These realities of on-the-ground programme implementation suggest that it may take several years, even decades, before the extent of treated cropland is large enough for downstream sediment reduction and associated benefits to become noticeable or measurable at the watershed outlet (Allen and Welch, 1967; Shields, 2008b).

Furthermore, identification of conservation effects on watershed-scale sediment yield is often rendered difficult by the large variability of runoff, soil erosion and sediment yield that shroud beneficial impacts of conservation practices. The large variability in hydrologic parameters is brought about by the sporadic and spatially variable nature of runoff-producing storm events, especially when combined with seasonally changing soil erosion potential due to agronomic activities. As a result of these many sources of variability, watershed runoff and sediment yield typically range over several orders of magnitude, and short-term conservation impacts at the watershed outlet are often hidden by this variability (Staff, Water Quality and Watershed Research Laboratory, 1983; Park *et al.*, 1994; Shields, 2008b). Also, runoff, soil erosion, and sediment yield are known to be sensitive to modest, yet persistent, multi-year precipitation variations often observed in annual precipitation records (Garbrecht *et al.*, 2006; Garbrecht, 2008). Thus, effects of persistently above normal precipitation on runoff and sediment yield can further overshadow beneficial impacts of conservation practices at a watershed outlet (Menzel *et al.*, 1978; Williams *et al.*, 1985), while persistently below normal precipitation may lead to low sediment yield that could erroneously be attributed to benefits of conservation practices.

In addition to difficulties brought about by conservation programme implementation and inherent variability of watershed runoff, the link between conservation and watershed sediment yield reduction is also often confounded by sediment storage effects within the watershed. Accelerated soil erosion on cropland areas may have been occurring for decades prior to implementation of conservation practices, with much of the eroded material re-deposited and accumulated in various locations within the watershed system. Conservation practices on cropland will reduce lateral sediment supply to channels, yet the watershed runoff system will usually respond by seeking a new regime equilibrium, remobilizing previously deposited sediments, or by eroding channel boundaries, thereby concealing beneficial conservation impacts at the watershed scale by shifting sources of sediment (Meade, 1988; Allen and Naney, 1991; Trimble, 1999; Walling, 1999). It may take some time to flush accumulated and stored sediments before the full effect of upstream soil conservation practices can be seen at the watershed outlet.

In light of these confounding effects (limited participation in conservation programmes, protracted implementation, temporal and spatial variability of soil erosion and sediment transport, and watershed sediment storage and flushing effects), sediment yield reductions are difficult to demonstrate at the watershed outlet within customary project durations of a few years. Hydrologic watershed models have been held by some as a way of alleviating these problems. With models, effects of various conservation scenarios on sediment yield reduction can be isolated by intentionally holding all other boundary conditions constant, and pre- and post-conservation treatment periods can be evaluated with identical climate drivers, thereby making results directly comparable with one another. These capabilities make hydrologic watershed models a practical approach to assess potential conservation impacts and benefits at the watershed scale (Santhi *et al.*, 2005; Gassman *et al.*, 2007; Jha *et al.*, 2007). However, models are based on simplifications and assumptions and do not reflect the full range of complexities, intricacies and feedback mechanisms encountered in the real world. Calibration and validation of watershed-scale sediment simulations remain difficult largely because long-term runoff and sediment yield measurements spanning an adequate number of years to demonstrate the impacts of pre- and post-implementation of conservation programs are rarely available. Also, watershed-scale sediment storage effects, conditions for and recurrence of sediment remobilization, the dynamics of shifting sediment sources, and the spatial and temporal propagation of perturbations in sediment budget within the watershed system are all very difficult to quantify, yet they are pertinent to the assessment of sediment yield at the watershed outlet (Meade and Parker, 1985; Meade, 1988; Trimble, 1999; Walling, 1999; Trimble and Crosson, 2000; Parson *et al.*, 2006; Vente *et al.*, 2007). Hence, sediment yield simulations at a watershed scale, while informative and insightful, are rarely verifiable and must be interpreted within the framework of model capabilities, assumptions and limitations.

In this study, conservation impacts on the Fort Cobb Reservoir watershed ($\sim$79′000 ha) were investigated by comparing runoff and suspended sediment yield measurements taken by the US Geological Survey (USGS) during 2004–2007 with similar measurements taken in 1943–1948. Suspended sediment yield reduction at the outlet of the Fort Cobb Reservoir watershed over 60 years was estimated and interpreted in terms of land use changes, conservation practices, urban development, and variations in climate. Findings illustrated that cumulative effects of many years of targeted and widespread soil conservation efforts in Central Oklahoma can, given enough time, result in a sizable reduction in sediment yield at the watershed outlet.

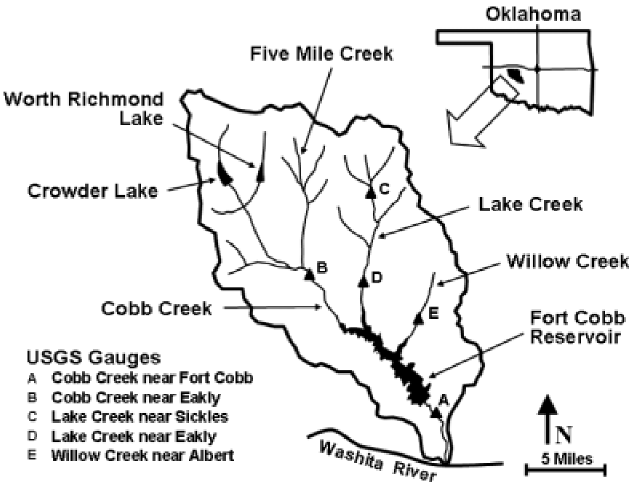

Figure 1. Fort Cobb Reservoir watershed outline and locations of US Geological Survey discharge and suspended-sediment gauging sites.

WATERSHED SUSPENDED-SEDIMENT AND DISCHARGE DATA

The Fort Cobb Reservoir in Central Oklahoma was constructed in 1959. It is a multipurpose reservoir for flood control, municipal and industrial water supply, and recreation. The reservoir receives inflow from a 787 [km^2] agricultural watershed consisting primarily of crop and grass land (see next section). The USGS operated up to five discharge-gauging stations on major tributaries, and collected instantaneous suspended-sediment and discharge data on a rainfall-runoff event basis at these stations (Figure 1; Table I). In particular, 30 instantaneous suspended-sediment and discharge measurements were taken at the Cobb Creek gauging station near Fort Cobb during 1943–1948, and 105 similar measurements were taken at four other gauging stations during 2004–2007. Measured discharges varied by gauging station depending on size of drainage area and covered the range from low to high flow conditions. All discharge and suspended-sediment samples were collected and processed by the USGS using the same standard procedures. Suspended sediment was measured by depth-integrated sampling, a method that was developed by the Federal Inter-Agency Sedimentation Project (FIASP) of the Inter-Agency Committee on Water Resources and has been in use since about 1939 (Edwards and Glysson, 1999). Thus, it is unlikely that a bias was introduced in suspended-sediment measurements due to sampling and sample processing procedures. Also, the seasonal distribution of the number of collected samples is very similar between 1943–1948 and 2004–2007 (Table II), thus minimizing the possibility of a bias that could have resulted from potential differences in seasonal distributions of sample numbers. The reader is further reminded that this study considers only suspended sediment which is the predominant sediment transport mode in the Fort Cobb watershed, and any reference to sediment yield, sediment load or sediment transport refers to suspended sediment only.

LAND USE AND CONSERVATION PRACTICES

Land use for 1943–1948

Storm *et al.* (2007) estimated prevailing land use in the watershed during years 1940–1957 based on historical crop data and land use distribution information. Crop coverage was obtained from 5-year county records compiled by the Bureau of Census, US Dept. of Commerce (for example, US Dept. of Commerce, 1952), and from the National Agricultural Statistics Service (NASS, 2007). Based on these data, Storm *et al.* (2007) estimated that in years 1940–1957, 72% of the watershed area was in cropland, about 25% in grassland (range and pasture land), and the remaining 3% in forest, roads, and urban areas. For the purpose of this study, the land use during 1943–1948 was assumed to be the same as the 1940–1957 land use estimated by Storm *et al.* (2007).

Conservation practices for 1943–1948

Conservation practices such as terraces, contour farming, strip farming, land use conversion, low-disturbance and no-till farming, drop structures, shelter belts, flood retarding structures, etc. are currently evident throughout the watershed. However, records detailing types and time of installation of conservation practices prior to the 1990s are not readily available in either the state offices of the Natural Resources Conservation Service (NRCS) (NRCS State Resource Conservationist, personal communication, February 2008) or the local conservation districts (NRCS District Conservationist, Anadarko Field Service Center, personal communication, February 2008). Historical accounts suggest that early conservation work in Oklahoma during the 1930s consisted primarily of widely

Table I. Identification number and characteristics of discharge and suspended-sediment gauging sites operated by the US Geological Survey.

Gauge name	USGS gauge number	Drainage area [km^2]	Period of observations	Number of data points	Data source
Cobb Creek nr Eakly	07 325 800	342	Nov 2004–Sep 2007	35	USGS
Lake Creek nr Sickles	07 325 840	49	Jun 2006	1[a]	USGS
Lake Creek nr Eakly	07 325 850	154	Nov 2004–Sep 2007	35	USGS
Willow Creek nr Albert	07 325 860	75	Nov 2004–Sep 2007	35	USGS
Cobb Creek nr Fort Cobb	07 326 000[b]	826	May 1943–Dec 1948	30	USGS

[a] Not a permanent suspended sediment collection site; only one suspended sediment measurement was made.
[b] After 1959, discharge below the dam reflects gate controlled discharge releases.

Table II. Seasonal distribution of number of suspended-sediment samples collected in the Fort Cobb watershed (all gauging stations) during years 1943–1948 and years 2004–2007.

Season	1943–1948 (%)	2004–2007 (%)
Winter (Jan, Feb, Mar)	20	26
Spring (Apr, May, Jun)	43	40
Summer (Jul, Aug, Sep)	17	14
Fall (Oct, Nov, Dec)	20	20

scattered demonstration projects, and that the height of the demonstration programme occurred in 1940 (Phillips and Harrison, 2004). Though conservation districts were formed throughout the State of Oklahoma from the 1930s through the 1950s to foster soil and water conservation, the districts tended to be poorly funded, loosely organized, and in many cases lacked expertise to implement suggested conservation practices (Phillips and Harrison, 2004). With the bombing of Pearl Harbor in 1941 and the onset of World War II, implementation of conservation practices was delayed to meet the need for food and fiber to support the war effort. During the early to mid-1940s, farmers put much of the land into crop production using conventional tillage practices. Thus, the extent of conservation practices in the Fort Cobb Reservoir watershed during the 1940s was rather limited and, for the purpose of this study, assumed to be essentially non-existent.

Land use for 2004–2007

At the beginning of the 21st century, three separate land use studies using remote sensing were conducted on the Fort Cobb watershed. Landsat Thematic Mapper (TM) data of June 2001 was evaluated by White *et al.* (2003). They found that about 51% of the watershed area was in cropland, 40% in grass, and the remaining 9% in other uses, such as forest, urban, roads, and water. In 2005, the USDA-ARS Grazinglands Research Laboratory, in cooperation with the Department of Geography at Oklahoma State University, conducted a study using Landsat TM data collected on multiple dates. Results from this study (unpublished) indicated that about 56% of the watershed was in cropland, 34% in grass, and the remaining area (10%) in other minor uses (Figure 2). In 2006, the USGS in Oklahoma conducted a land use study in the watershed using remotely sensed data collected from multiple sensing platforms for several dates of imagery collected in 2005. Results from this study (unpublished) estimated that about 48% of the watershed area was in cropland, 35% in grass, with about 17% percent of the remaining area in other minor uses. These studies, which used different remote sensing platforms and/or dates of imagery, indicate that the land area in the major land use categories remained rather stable from 2001 through 2005. Thus, it was assumed that the average of the land use estimated by these three studies adequately represented the land use for the 2004–2007 timeframe, namely 52% in cropland, 36% in grass, and 12% in other land uses (urban, forest, roads, water, etc.). Percent of drainage area above each

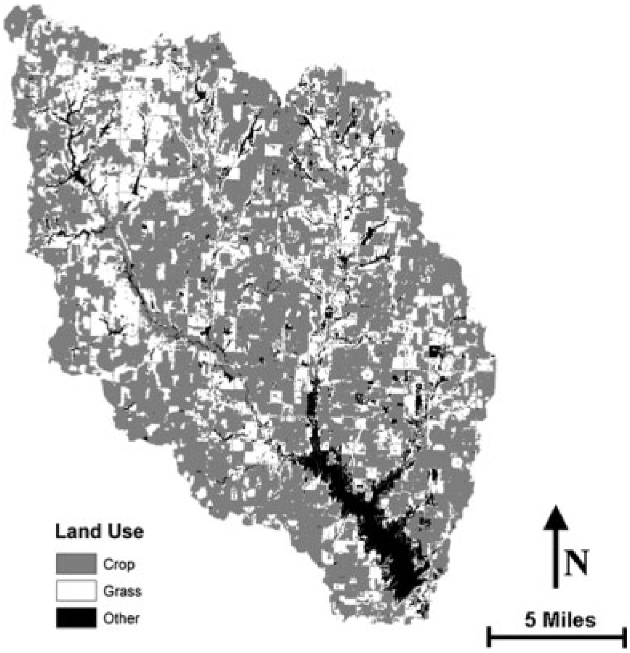

Figure 2. Spatial distribution of land use in the Fort Cobb watershed during year 2005. Crop land includes all crop producing fields independent of tillage type; grass land is primarily range and pasture land; and other represents mostly urban areas, roads, forests and water surfaces.

Table III. Percentage of drainage area above each gauging station (locations B, D and E in Figure 3) in a given landuse category (cropland, grassland and other).

Gauging station	Cropland (%)	Grassland (%)	Other (%)
Cobb Creek near Eakly (B)	54	39	7
Lake Creek near Eakly (D)	53	38	9
Willow Creek near Albert (E)	54	37	9

gauging station (Cobb Creek near Eakly, Lake Creek near Eakly, and Willow Creek near Albert) that is in the crop, grass or other land use category is given in Table III and show a similar distribution over the three drainage areas considered.

Conservation practices for 2004–2007

Conservation practices reported in this section were estimated based on authors' interviews of South Caddo County Conservation District personnel, a Conservation Specialist of the Oklahoma Conservation Commission, Caddo County, and a Resource Conservation and Development Coordinator of the Great Plains Area (February and April 2008). The central and eastern portion of the Fort Cobb watershed is in Caddo County. This county covers approximately 70% of the watershed area, contains soils that are erosion prone and actively eroded, and are believed to contribute the bulk of sediments eroded from cropland. In contrast, the western 30% of the watershed area is characterized by more stable soils, less cropland, and proportionally more forest and range land. Therefore, land use conversion, agronomic activities, and conservation efforts in Caddo County were the primary focus of this sediment yield investigation.

Interest in soil conservation and applications for conservation funds in Caddo County is high compared to some other counties in Oklahoma. As of spring 2008, the waiting list for conservation funds consists of around 300 applicants, and the waiting time was about 2 to 4 years, depending mostly on availability of limited funding and ranking of individual conservation scores. As a result of this interest in soil conservation, 80% to 90% of cropland that needed terraces has been terraced over the last 50 years, and over the last decade about 50% of the cropland was in conservation tillage or minimum disturbance tillage. Conservation funds assisted with gully reshaping on 6·6 [ha] and installation of 39 grade stabilization structures. Additional soil conservation practices were implemented without cost sharing assistance.

In addition to cropland erosion control, selected channel bank sections were stabilized, small impoundments were constructed, and a number of gravel/dirt roads were paved. It was estimated that about 9 miles of channels have been fenced over the last 5 years to prohibit cattle from destabilizing channel banks and to prevent head cuts into pasture lands. In addition, 30 creek jacks were installed to stabilize a channel bank. Despite these and earlier efforts, several long unstable channel reaches still exist upstream of the reservoir and were identified by a geomorphic assessment conducted in 2007 by the USDA-ARS National Sedimentations Laboratory of Oxford, Mississippi (Simon and Klimetz, 2008). Unstable channel reaches include the entire length of Five-Mile Creek, Cobb Creek below gauging station B, the middle and upper reaches of Lake Creek, and the upper reaches of Willow Creek (Figure 1). The stability of channels in the 1940s could not be established because historic records describing the state of channels in the Fort Cobb watershed did not exist or could not be found. With regard to impoundments, eight Soil Conservation Service (now NRCS) flood-retarding structures (including Crowder Lake and Worth Richmond Lake) were constructed in the late 1950s in the north-western portion of the watershed. Total upstream drainage area controlled by these impoundments was about 14% of the watershed area. Not only do these impoundments trap sediments but they also modify runoff hydrology by reducing channel peak flows, thereby indirectly reducing suspended-sediment transport capacity. With regard to roads, a windshield survey of road type and erosion problems determined that about half of the roads in the watershed were paved and the other half were classified as gravel or dirt roads. Dirt roads are particularly prone to erosion and require ongoing maintenance. It is believed that most of the presently paved roads were paved between 1958 and 2004. Despite all these soil conservation efforts, controlling erosion on the fragile soils in Caddo County will continue to be a priority.

Suspended sediment-discharge rating curves

Thirty instantaneous suspended-sediment and discharge samples were collected during 1943–1948 at the Cobb Creek gauging station near Fort Cobb (location A) (Table I; Figure 1). Sample values were divided by upstream area (i.e. converted to unit area values) to facilitate data comparison between gauging stations. Discharge values ranged from 0·0007 to 0·33 [$m^3/s/km^2$] and sediment values ranged from 0·007 to 44·0 [$Mg/d/km^2$]. These data reflected watershed response under 1943–1948 pre-conservation conditions. The 105 sediment and discharge measurements taken at the four other gauging stations during 2004–2007 (Table I; Figure 1) were also converted to unit area values. The gauging stations were Lake Creek near Sickles, Lake Creek near Eakly, Willow Creek near Albert, and Cobb Creek near Eakly (Figure 1). Discharge values ranged from 0·0003 to 0·66 [$m^3/s/km^2$] and sediment values ranged from 0·002 to 500·0 [$Mg/d/km^2$]. These data reflected watershed response under 2004–2007 post-conservation conditions, that is after a broad range of conservation practices were implemented in the second half of the 20th century.

A second-order regression was fitted ($r^2 = 0{\cdot}87$) to the 1943–1948 suspended sediment versus discharge data at gauging location A (Figure 1), thereby producing a suspended sediment-discharge rating curve for pre-conservation conditions representative of the 1940s land use and management (Figure 3). A separate suspended sediment-discharge rating curve, representing land use and conservation conditions of 2004–2007, was developed from measurements taken in 2004–2007 at four separate gauging stations (locations B, C, D and E on Figure 1). A plot of suspended-sediment and discharge measurements at locations B, C, D and E showed a near perfect overlap (Figure 4), thus a single second-order regression curve ($r^2 = 0{\cdot}97$) was selected to represent the suspended sediment-discharge relationship at the four gauging stations. The fact that a single rating curve represented four drainage areas ranging from 49 to 342 [km^2] (Table I), suggested that this rating curve is likely representative for a wide range of drainage areas within the watershed. Furthermore, the upstream drainage area of the four gauging stations covers about 70% of the watershed area above the Cobb Creek gauging station near Fort Cobb. These considerations led to the assumption that the 2004–2007 sediment-discharge rating curve was a fair approximation of the rating curve that would have existed at the Cobb Creek gauging station near Fort Cobb (location A) if the reservoir had not been constructed in 1959. Thus, two rating curves were developed for location A: one that applied for the 1943–1948 land use and management conditions (pre-conservation), and another that reflected the 2004–2007 land use and management conditions that included all conservation practices implemented in the second half of the 20th century (post-conservation).

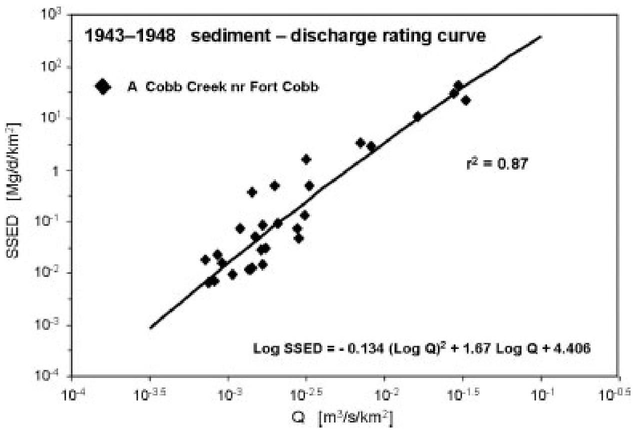

Figure 3. Instantaneous suspended-sediment (SSED)-discharge (Q) rating curve at Cobb Creek near Fort Cobb representative for 1943–1948 land use and conservation conditions.

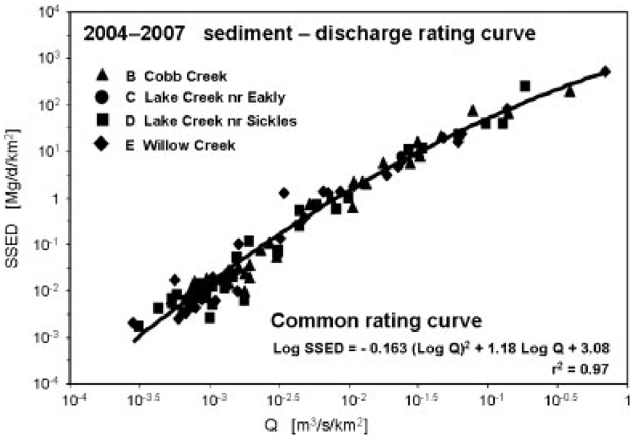

Figure 4. Instantaneous suspended-sediment (SSED)-discharge (Q) rating curve at Cobb Creek near Fort Cobb representative for 2004–2007 land use and conservation conditions.

Suspended-sediment yield reduction

The above-developed rating curves were based on instantaneous discharge and suspended-sediment values. While instantaneous values are not the same as daily average values, the relationship produced by instantaneous values is generally very similar to that based on daily average values, especially since instantaneous measurements were take at any time during the daily hydrograph. Thus, for the objectives of this study, it was assumed that the above-developed relationships adequately approximated relationships between daily average discharge and suspended sediment load. With this assumption, annual suspended-sediment yield at location A was estimated for pre- and post-conservation conditions by evaluating the two suspended sediment-discharge rating curves with observed 1940–1957 daily discharge values. The 1940–1957 record was the only available long-term continuous daily discharge record. Evaluation of the 1943–1948 sediment-discharge rating curve (pre-conservation conditions) produced an average annual suspended-sediment yield of 760 [Mg/yr/km^2], whereas, based on the 2004–2007 sediment-discharge rating curve (post-conservation conditions), the estimated average annual suspended-sediment yield was 108 [Mg/yr/km^2]. This latter sediment yield represented that sediment yield that would have existed if the 1940–1957 precipitation and runoff occurred with the 2004–2007 land use and conservation practices in place. The suspended-sediment yield under post-conservation conditions was over half an order of magnitude (factor of seven) less than that for pre-conservation conditions. This reduction was attributed to changes in land use and conservation practices between 1943–1948 and 2004–2007, as elaborated in the next section.

It would have been insightful to estimate annual suspended-sediment yield using more recent daily discharge values at the Cobb Creek gauge. However, the Fort Cobb Reservoir dam was constructed in 1959 a few miles upstream of the gauging station. Thus, after 1959, observed discharge at this gauging station reflected gate-controlled reservoir releases during high runoff events and did not represent natural watershed runoff patterns. Hence, the discharge record after 1959 was unsuitable for intended use in this investigation. Nevertheless, it should be recognized that application of the 1940–1957 pre-conservation discharge to the 2004–2007 post-conservation land use and management conditions inherently led to an over-estimation of annual suspended-sediment yield for 2004–2007. This over-estimation is the result of neglecting increased infiltration and reduction in surface runoff volume and peak usually associated with conservation practices. Therefore, the previously calculated reduction in watershed suspended-sediment yield is a conservative estimate, and the reduction would have been larger if beneficial changes in runoff hydrology due to conservation practices were accounted for. Unfortunately, these beneficial changes in runoff hydrology could not be quantified with available observational data.

DISCUSSION

Changes in watershed sediment yield are often attributed to land use conversion, conservation practices, stream channel stabilization, urbanization, and/or climate variability, among the most important factors. With regard to urbanization, there are only two small rural communities in the watershed, and these have not grown much over time. Thus, urbanization was probably not an important factor affecting watershed suspended-sediment yield. The effects of climate variability and any associated change in hydrologic and runoff regime on sediment yield were eliminated by evaluating the two rating curves with identical 1940–1957 daily discharge data. As a result, previously reported persistent multi-year precipitation variations (Garbrecht and Schneider, 2008) were not an issue to contend with because the use of identical daily discharge values for evaluating both rating curves necessarily implied the same weather and climate. Observed suspended-sediment and discharge data underlying the rating curves were also unlikely to be significantly affected by climate variations, because decisions when to sample and how often to sample was not based on storm size or frequency, nor was it based on any climatic considerations. Low-flow samples were taken during a dry period, low channel flow conditions, and at different times and seasons during the year (Table II). High-flow sampling was initiated whenever a sizable surface-runoff producing storm was forecasted, though in hindsight the forecast storm may not always have produced a sizable surface runoff over the area of interest.

Having ruled out urbanization and climate variations as likely cause for the reduction of watershed suspended-sediment yield, one is invariably led to the conclusion that land use conversion and implementation of conservation practices must have produced the sediment yield reduction. Indeed, starting in the 1950s and through the beginning of the 21st century, about 20% of erosion-prone cropland was converted to grassland. A review of sediment yield data from side-by-side experimental watersheds at the Grazinglands Research Laboratory (GRL) in El Reno (Garbrecht, 2000), located about 30 miles east of the Fort Cobb watershed, showed two orders of magnitude difference in sediment yield from watersheds planted in conventionally tilled winter-wheat and those in native prairie. It follows that sediment yield from grassland is, for most practical purposes, insignificant compared to that from cropland. This was assumed to also apply for the sandy and erodible soils in Caddo County. Thus, as a first approximation and on a unit area basis, soil eroded from cropland represented the bulk of the soil delivered from overland erosion to channels. It follows that conversion of the 20% of most erosion-prone cropland to grass land reduced the overall sediment loading from cropland to channels by more than 20% (because these 20% cropland delivering the most sediment).

Also, over the last decade, conventional tillage has given way to conservation tillage or no-till on about 50% of the cropland. Again, based on data from side-by-side experimental watersheds at the GRL (Garbrecht, 2000), a sediment yield reduction of about a factor of two was observed between conventional tillage and conservation tillage. Thus, implementation of conservation tillage further reduced sediment delivery from cropland to channels. Additional reductions in soil erosion and sediment yield can be attributed to terracing of cropland, gully shaping, grade control structures, channel stabilization efforts, sediment trapping by impoundments and reservoirs, and county road surfacing.

Taking all the above considerations into account, there appears to be little doubt that the cumulative and integrated effects of all conservation practices implemented in the second half of the 20th century reduced soil erosion and, over time and with some delay, led to the 2004–2007 observed suspended sediment yield reduction at the watershed outlet.

SUMMARY AND CONCLUSIONS

Effects of conservation practices on watershed suspended-sediment yield were investigated for the Fort Cobb Reservoir watershed. The USGS measured stream suspended-sediment and discharge during 1943–1948 and again during 2004–2007, after extensive conservation measures were implemented on the watershed in the second half of the 20th century. A suspended sediment-discharge rating curve was developed with the 1943–1948 measured data which reflected land use conditions prevailing during that time, also called the pre-conservation period. A second suspended sediment-discharge rating curve was developed with the 2004–2007 data which reflected land use and conservation conditions prevailing during that time, called the post-conservation period. Daily watershed suspended-sediment yield was estimated by use of rating curves and 1940–1957 daily discharge records near the watershed outlet. Evaluating both rating curves with the same daily discharge eliminated any effects of changes in runoff characteristics due to differences in climate between the 1940s and the early 21st century. Annual suspended-sediment yield at the watershed outlet, estimated by summing daily suspended-sediment yield, was 760 [Mg/yr/km^2] and 108 [Mg/yr/km^2] for the pre- and post-conservation period, respectively.

The substantial reduction in annual suspended-sediment yield between 1943–1948 and 2004–2007 was related to land use conversion and implementation of soil conservation practices. Land use conversion was from cropland to range and pasture land, and soil conservation practices included conservation tillage, terracing of cropland, gully shaping, grade control structures, channel stabilization, sediment trapping by water impoundments, and county road surfacing. The gradual implementation and cumulative effects of this broad range of conservation measures over a 60-year time span was very likely the primary cause of the estimated reduction in today's watershed suspended-sediment yield over that from the 1940s. This study demonstrated that while it may be difficult to measure sediment yield reductions due to conservation impacts during the short time span of a conservation project, targeted, widespread and sustained conservation efforts generally will, over time, reduce sediment yield at the watershed outlet, as was the case for the Fort Cobb Reservoir watershed.

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